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"Method for modelling life of a piece of equipment in an industrial plant,  
method for performing maintenance on an industrial plant and maintenance-  
system"

15 This invention relates to a method for modelling life of a piece of equipment  
in a furnace. More particularly, the invention relates to a method for model-  
ling coil life in a furnace.

Coils in furnaces are known to fail after a time of usage, wherein coil failure  
20 is defined as a coil crack or a rupture. Since the end of the coil life caused  
by the failure as a rule does not coincide with the end of the desired use of  
the furnace, the coil needs to be replaced in order to further use the furnace.  
Especially in large chemical plants coils of considerable size are used that  
are very expensive. On the other hand, every day of non-operation of a fur-  
25 nace caused by replacement of the coil and/or waiting for a newly ordered  
coil to arrive is also a great loss of potential yield. Operators of furnaces are  
thus confronted with the question of when to buy a new coil, whether to keep  
this coil as a spare and when to replace the coil in use with the newly bought  
one. Costs could be minimized, if the exact date of coil failure could be  
30 determined. Since coil life is dependent on a multitude of influencing-

parameters, most of which even vary during the coil life, such as feed rate of material fed into the furnace to be heated, a way of determining the exact date of coil failure has not yet been found. For this reason statistical methods are used to predict an expected coil life.

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One statistical method used is the so-called Weibull analysis, which on some items generates a characteristic bathtub failure curve. This failure curve can be used to determine the probability of the item failing over time, giving operators an indication on when the item failure is to be expected with great probability. Because of the many failure modes possible for a coil in a furnace, the Weibull analysis has been found to be limited in its use for coil life modelling.

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These problems also arise when modelling the life of other pieces of equipment in the furnace. Here also, no reliable way has been found to model the life of this piece of equipment.

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It is thus an object of the current invention to provide a method for modelling life of a piece of equipment in an industrial plant, especially in a furnace, which provides a better prediction for an expected life. Furthermore it is an object of the current invention to provide a method for performing maintenance on an industrial plant and a maintenance-system which allow considerable cost reductions for operating the industrial plant.

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These objects are solved by the methods and the maintenance system as defined in the independent claims. Further embodiments are defined in the dependent claims.

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The inventors have realized that the influence of each of the multitude of influencing-parameters relevant for the life of a piece of equipment of an industrial plant thus, can best be found by use of multiple regression analysis. Thus a model for coil life that expresses an expected life in terms  
5 of variables relevant for the life is best found by use of an multiple regression analysis.

Multiple regression analysis is a known statistical method and shall thus not be described in detail. It is used to generate a formula of the type  
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$$Y = b_0 + b_1X_1 + b_2X_2 + \dots + b_kX_k + E \quad (1)$$

Where  $Y$  = value to be predicted

$b_0$  to  $b_k$  = constants

15  $X_1$  to  $X_n$  = any of all variables or functions of a few basic variables

$k$  = maximum number of constants

$E$  = the unexplained error.

20 The constants are found by the multiple regression analysis using data from already completed processes. The equation thus relates the desired value to predict directly to the variables.

Using multiple regression analysis gives the advantage of providing an  
25 equation that can take a multitude of influencing-parameters into account. The desired value to predict is thus not determined solely in its dependency on a single influencing-parameter, which has proved to be inadequate, but on many influencing-parameters. Thus the different influences parameters

have on the life of a piece of equipment, such as prolongation or shortening, can all be accounted for, giving a better prediction of the life to be expected.

Advantageously the influencing-parameters that are put into the equation  
5 are pre-selected according to their correlation and their significance. Some influencing parameters or terms can correlate among each other (exact, singular or multiple linear), making the prediction model unstable, over-fitted and over-sensitive. Small random changes in data can thus cause huge unrealistic predictions. This is because the variables are not occupying all  
10 directions of the regression space. Also influencing-parameters can be non-significant. Their inclusion can give false indication of the goodness of the fit, give higher variance in the equation coefficients and increase variance in the predictions itself. Thus, using all possible influencing-parameters in a search for the best prediction possible leads to a bad or worthless prediction and is  
15 thus advantageously not performed.

Trying every combination of the influencing parameters available in the database in order to identify the combination that leads to a model with the best performance is a very time consuming process and needs very powerful  
20 hardware to be undertaken. Thus it is advantageous in order to reduce the equipment necessary for the modelling-method according to the invention to only try equations based on certain, selected combinations of variables in order to find the best model.

25 A first step for selecting the variable combination is obtaining information on the correlation the individual values for a single variable in the database have among each other and obtaining information on the significance of the variables on the value to be predicted. This is done by determining signifi-

cance values and correlation values. Advantageously, as significance value the Prob>F value is used. The lower this value is, the more significant the influencing-parameter is. Also preferred, as correlation value the VIF-value is used. The lower the VIF value, the lower the correlation of the influencing-parameter in comparison to the other influencing-parameters. According to a special embodiment of the invention, these Prob>F values and VIF values are obtained from all influencing-parameters in their relation to the influencing-parameters that are already used in a tried equation. This helps determining, which influencing-parameter is introduced into the equation as next influencing-parameter. According to the invention, of the parameters not yet introduced into the equation, the parameter that has the lowest significance value (Prob>F), ie. the influencing-parameter that has the highest significance, and at the same time has the lowest correlation value (VIF), ie. the influencing-parameter with the lowest correlation to the parameters already in the equation (equation-parameters) is used.

At the same time, the inventors have realised, that only introducing the influencing-parameter, which at each step of generating the equation shows the lowest absolute values for the significance value and the correlation value does not necessarily lead to the best model. Accordingly, the inventors have created a way of successively introducing and excluding influencing-parameters from the equation to be generated on the basis of predetermined rules.

The multiple regression analysis, that is part of the method for modelling the life of a piece of equipment, the method for performing maintenance and is used in the maintenance-system according to the invention, uses the following steps:

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- a) determining a start value as first influencing-parameter,
- b) generating a current equation based on the start value and thereby entering the start value as equation-parameter into the equation,
- c) determining a significance value and a correlation value for each influencing-parameter with respect to the equation-parameter(s),
- d) selecting as new equation-parameter the influencing-parameter with the highest significance and the lowest correlation that is not an equation-parameter and has according to a parameter-database not been used as equation-parameter in combination with the equation-parameters of the current equation,
- e) replacing the current equation with a new current equation by generating the new current equation based on the equation-parameters now including the new equation-parameter by means of multiple regression analysis based on the values of the value-database,
- f) recording in parameter-database the combination of influencing-parameters already used as equation-parameters and the order of introducing the equation-parameters into the current equation,
- g) calculating the performance of the current equation and recording this performance with reference to the equation-parameters in the current equation in a performance-database

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- h) repeating the steps c) to g) until for none of the influencing-parameters that are not equation-parameters the significance is higher than a predetermined value while at the same time the correlation is lower than a predetermined value or either the significance of an equation-parameter has become  
5 lower than a predetermined value or the correlation of an equation-parameter becomes higher than a predetermined value,
- i) excluding the influencing-parameter that according to the parameter-database was last selected as new equation-parameter and replacing the current  
10 equation with a new current equation by generating the new current equation based on the equation-parameters that remain after exclusion of the last selected influencing-parameter by means of multiple regression analysis based on the values of the value-database,
- 15 j) repeating the steps c) to i) until the influencing-parameter to be excluded is the start value,
- k) selecting from the database the set of equation-parameters which provided the best performance and generating a final equation by use of multiple regression analysis based on these influencing-parameters and their  
20 individual values in the value-database.

Advantageously, the start value used is the intercept, ie. the mean of the values available in the database for the parameter to be modelled. The  
25 equation that uses the intercept as influencing-parameter that is introduced as equation-parameter is the most basic way of modelling life of a piece of equipment in an industrial plant, ie. setting the expected life to be equal the mean of all the life-spans that are recorded in the database.

The significance and the correlation of the available influencing parameters is advantageously determined using the Prob>F value and the VIF value, whereby a low Prob>F value shows a high significance and a low VIF value  
5 a low correlation.

In order to improve the most simple equation, this method relies upon introducing further (new) influencing-parameters as equation-parameters into the equation. However, the way of selecting new equation-parameters is made  
10 dependent on rules that prevent redundancies in calculation and unnecessary calculations, thereby advantageously reducing the calculation time necessary.

According to the first rule, no influencing-parameter is selected as new  
15 equation parameter that is already a equation parameter of the equation in its current form. Furthermore no influencing-parameter is used that has already been made basis for a previously sampled equation in combination with the equation parameters currently in the equation. This prevents redundancies that occur, when - for example - it is considered to introduce  
20 of a numbered list of influencing-parameters the third influencing-parameter into an equation that is based on the first influencing-parameter and where a combination of the third influencing-parameter and the first influencing-parameter as equation-parameters has already been sampled. In this case the third influencing-parameter would not be selected, as it would not lead to  
25 a new combination.

According to a second rule, no influencing-parameter is selected, which is insignificant and/or correlated to the equation-parameters already in the



equation relative to predetermined rules. These could be that no influencing-parameter is introduced that has a Prob>F value larger than 0,05 and a VIF-value of more than 5. These predetermined values obviously being of free choice dependant on how accurate the model is desired to be. This measure  
5 prevents unnecessary calculation procedures for equations with combinations of equation-parameters that are correlated or where the introduction of a new equation-parameter does not help predicting the response.

According to a third rule, not only the best performing influencing-  
10 parameters at each step are considered to be introduced as equation-parameters, but all possibilities of introduction of influencing-parameters that satisfy the above second rule are considered and sampled. This is a particular advantage of this method, since it has been shown that only combining the best performing influencing-parameters at each stage does  
15 not lead to the best model. This includes that after an equation on the basis of the best performing influencing-parameter has been sampled, further equations are successively sampled based on the respective selection of the remaining influencing-parameters that meet the criteria of the above second rule.

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The performance of the sampled equation is calculated using standard statistical methods, ie. by calculating and recording values for the whole equation for R<sup>2</sup>, RMSE, max. Prob., max. VIF, F-ratio, Prob>F, SE of the model and SE to the fit. The performance of each sampled equation is recorded in  
25 a performance-database with reference to the combination of equation-parameters that was used to obtain this performance. This allows the best performing equation to be selected after having sampled all equations that are possible according to the above rules.

Though the model-method according to the invention is described with reference to modelling life of a piece of equipment of an industrial plant, more particular to modelling coil life in a furnace, it is to be understood that this method provides good results for every variable that is to be predicted in any process using sets of values in databases. Accordingly, mention of a piece of equipment in a furnace is to be understood as representative for every variable in any process. The method according to the invention is thus not to be understood to be limited to uses in furnaces, but to be understood to be applicable in modelling any other variable, too.

The invention has been tried with good results for predicting the life of a piece of equipment in a furnace, especially for coil life and is advantageously used for this.

For cases where each influencing-parameter has a high level of significance and a low correlation, it is advantageous to start with an equation generated by multiple regression analysis that is based on all influencing-parameters and to exclude certain parameters from this equation according to specific rule. This can be done according to the following steps:

a) generating a current equation based on the all influencing-parameters and as further influencing-parameter a determined start-value as equation-parameters by means of multiple regression analysis based on the values of the value-database,

b) determining a significance value and a correlation value for each influencing-parameter with respect to the equation-parameters,

- 5 c) selecting as new unnecessary influencing-parameter the equation-parameter with the lowest significance and the highest correlation that is according to a parameter-database not an unnecessary influencing-parameter and whose removal as equation-parameter does according to a parameter-database not lead to a combination of equation-parameters that according to the parameter-database has previously been used ,
- 10 d) replacing the current equation with a new current equation by generating the new current equation based on the set of equation-parameters from which the new unnecessary influencing-parameter has been removed by means of multiple regression analysis based on the values of the value-database,
- 15 e) recording in the parameter-database the combinations of parameters used and the order of removal of unnecessary influencing-parameters from the current equation,
- 20 f) calculating the performance of the current equation and recording this performance with reference to the equation-parameters in the current equation in a performance-database,
- 25 g) repeating the steps b) to f) until for none of the influencing-parameters that are equation-parameters either the significance is lower than a predetermined value or the correlation is higher than a predetermined value or for one of the unnecessary-parameters the significance has become higher than a predetermined value while at the same time the correlation has become lower than a predetermined value.

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h) re-introducing the influencing-parameter that according to the parameter-database was last removed as new unnecessary influencing-parameter,

- 5 i) repeating the steps b) to h) until either the influencing-parameter to be excluded is the start value or until no equation-parameter that has a significance that is lower than a predetermined value or a correlation that is higher than a predetermined value can be excluded without leading to a combination of equation-parameters that has already been sampled,

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j) selecting from the database the set of equation-parameters which provided the best performance and generating a final equation by use of multiple regression analysis based on these influencing-parameters and their individual values in the value-database.

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In this alternative, when it is determined, whether the significance is lower than a predetermined value and significance is measured by the Prob>F value, it is obvious to the man skilled in the art, that the determination if an influencing-parameter is insignificant is determined by testing whether

20 Prob>F is larger than a predetermined value.

For determining the coil life of a coil in a furnace, the variables influencing the coil life are mainly variables that reflect the operating conditions and the design of the furnace.

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Operating conditions are for example the coil installation date, the quantities of products fed through the furnace and the coil, temperatures in the furnace and on the outside, the kind of products feed through the furnace, inspection

results, for example on coil deformation, coil wall thickness and/or coil diameter, rates and ratios of mechanical cleaning, cool down and start up of the furnace.

- 5 Furnace design variables are for example the site location, feed pipe layout, furnace type, furnace placement, coil placement, coil type, coil material and coil manufacturer. Other pieces of information that can have an influence on coil lifetime and that can be quantified nominally or continuously can additionally be introduced. For modelling coil life in a furnace of a chemical process, especially in ethylene production, operating conditions can among others be described by the quantities of dilution steam, fuel gas and feed; the temperatures of the coil skin, the transfer line exchanger, the coil outlet, the crossover and the stack; the kind of the feed, the quality of the feed (with respect to contaminants), the flow of the feed (with respect to amount and fluctuations); the rates and ratios of mechanical cleaning, decoke stops, air/steam ratio during decoke, feed switches, cool down and start up; inspection results on carburisation, coil deformation, coil diameter, coil wall thickness; and design parameters.
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- 20 Since the model will be used for predicting life of a piece of equipment in a furnace in a continuous process, in which the values of the influencing-parameters might change during operation, the influencing-parameters can be defined as mean values of the parameters and an extra variable per parameter can be introduced as representation of how the parameter has changed during coil life, possibly by use of ratios.
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In a preferred embodiment of the method for determining the probable life of a piece of equipment in a furnace, a formula of the type described above

under (1) is put together, expressing the expected life in terms of variables relevant for the life and factors of influence, which are the constants. For modelling, influencing-parameters (variables) that are relevant for the life of the piece of equipment are identified, advantageously by use of statistical methods, ie. by determining the significance and the correlation of the variables. Then the data for the variables is collected from already completed processes, ie. processes where the piece of equipment has already failed. Hereafter, a further step can be advantageously added, in order to determine the relevance of the influencing-parameters for which the data has been collected, advantageously by use of statistical methods. This data collection includes data on the actual life achieved in the completed process and the replacement reason. The more data can be collected for each individual process, the more precise the model will become. Also will the accuracy of the model be increased, the larger the number of data sets is, ie. the larger the number of completed processes that are researched is. A multiple regression analysis will be performed on these data sets in order to generate the constants (factors of influence). Finally these factors of influence can be put into the formula (1) and thus provide a model for coil life. For a newly installed coil or a coil already in operation, values for the influencing parameters can be fed into the equation, which will then give a value of an expected coil life. Furthermore, if a certain life is desired, the method for determining the probable life can be used to establish operating conditions under which the furnace has to be operated in order to achieve the desired life.

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Preferably the data is taken from a furnace control system and/or the operational history of a furnace and/or the design of the furnace. Especially using a furnace control system as source for data makes modelling of the life of

the piece of equipment simple, as the furnace control system generally stores the data in electronic form, which can easily be used in the multiple regression analysis and which can also easily be used to be fed into the model equation, once this has been derived.

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Large benefits through minimisation of costs are achieved in plants with furnaces, if the above model is integrated into a method for performing maintenance on the furnace. Due to the increased accuracy of the predicted life of the piece of equipment, purchase of a replacement-piece and cool down  
10 of the furnace for replacement can precisely be planned. This makes storing extra pieces obsolete, thus reducing the amount of capital bound by unused equipment. Furthermore, the furnace downtimes and the maintenance frequency can be decreased, as well as the production continuity can be increased.

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The method for performing maintenance on a furnace can consist of a system, into which operational data and/or design data of the furnace is fed and which generates a value for an expected life. When the actual life equates to the predicted life, the method for performing maintenance requires a change  
20 of the coil. Alternatively, values that are derived from the predicted life can be used. For example, replacement of the coil can take place a week before the actual life equals the predicted life.

The operational data fed into the system can be taken from a furnace control  
25 system and used to fill the variables in a formula of the type (1) which is stored in the system and which has previously been found by multiple regression analysis in the way described above.

The method for performing maintenance can be further improved, if it is designed to be self-learning. That is, if the method allows for modification of the formula used to calculate the expected life. Preferably, collected data for variables relevant for the life of a piece of equipment from a furnace which  
5 failed pre-predicted is used to modify the factors of influence. If the piece, on which the method for performing maintenance has been applied, fails before the predicted of life, the data that has been collected for the influencing-parameters over the coil life should be used to modify the factors of influence in order to adapt the formula better to the furnace and the actual  
10 running conditions. Especially in a big plant, where the method for performing maintenance is used for a multitude of furnaces, this way of adapting the formula to the actual conditions of the plant will constantly improve the method. One way of improving to modify the factors of influence is to run a new multiple regression analysis in the system, using stored data  
15 from completed processes that is supplemented by the new data. Instead of waiting for the coil to fail and to modify the factors of influence only after the coil has failed, modification of the factors of influence can also occur pre-failure. The fact that with a coil in operation, operation parameters which the coil has already been subjected to have not caused a failure is important  
20 knowledge that can be fed into the multiple regression analysis to improve the accuracy of the model.

According to an aspect of the invention, a maintenance-system is provided that consists of a calculating unit, a storage unit, an input unit, whereby

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- a formula of the type used in multiple regression analysis that expresses an expected life of a piece of equipment in a furnace in



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terms of influencing-parameters relevant for the life and factors of influence is stored in the storage unit,

- the calculating unit is adapted to read the formula from the storage unit,
- 5 - the calculating unit is adapted to apply the formula to values for the variables received from the input unit and/or read from the storage unit so as to generate a value for an expected life.

Such a maintenance-system can be used easily and has the further  
10 technical advantage that operational parameters that are generated in a furnace control system, that runs electronically and stores data electronically can easily be read into the system via an input unit that runs electronically allowing for an online, continuous calculation of the expected life.

15 Additionally the calculating unit can be adapted to compare the value for an expected life with a value for the actual life generated from data received from the input unit and/or read from the storage unit to generate a value for remaining life. The value for remaining life gives a figure that is easy to handle when planning the replacement of the piece in use. Also prediction confi-  
20 dence limits, the survival and failure probability and an estimate for the future replacement costs can be generated.

The method for modelling coil life in a furnace, the method for performing maintenance on a coil in a furnace and the maintenance-system according  
25 to the invention can advantageously be used in ethylene production processes and plants. Since ethylene is one of the most produced chemicals, sufficient historical data on coil life for this production process is available, which allows for generating a very accurate model.

An embodiment of the present invention will now be described, by way of an example, with reference to the accompanying drawings, in which:

- 5 Fig. 1 is a representation of the way influencing-parameters are introduced into the equation in order to obtain the combination of influencing-parameters giving the best prediction;  
Fig. 2 to 14 are print-outs of results showing the significance and correlation of each influencing-parameter in relation to the influencing-  
10 parameters in the equation and showing the performance of the current equation.

The example shown by use of the figures is used to exemplify how the method for determining the probable life of a piece of equipment in a furnace  
15 according to the invention is applied. By means of the method according to the invention, the probable coil life of a coil in a furnace is determined.

As influencing-parameters relevant for the coil-life, % Butane tn, % Co-crack tn, % GasCond. tn, % LPG tn and % Naphtha tn are selected. They repre-  
20 sent what percentage of the total feed applied to a coil was of the different types: butane (% Butane), a mixture of regular feed (e.g. Naphtha, LPG) and returned/recycled off-grad product, suitable to be cracked again (% Co-Crack), condensated gas taht is obtained with the extraction of petroleum (% GasCond), liquefied petroleum gas (% LPG) and Naphtha (% Naptha). For  
25 these variables, data is collected in a value-database. Here individual values for the coil life (ie. the value when the coil failed (cracked)/is exchanged) are related to the respective individual values of the influencing-parameters that led to the individual coil life.

In order to determine the probable coil life, a multiple regression analysis is performed on the collected data. However, the multiple regression analysis is not performed on all influencing-parameters, but tried on several combinations of influencing-parameters in order to obtain the best model.

For the following, the influencing-parameters are referred to by numbers, influencing-parameter 1 being % Butane tn, influencing-parameter 2 being % Co-crack tn, influencing-parameter 3 being % GasCond. tn, influencing-parameter 4 being % LPG tn and influencing-parameter 5 being % Naphtha tn.

As shown in Fig. 1, starting from the intercept, ie. the mean value of all coil lives in the database, as start value that is entered as first influencing-parameter into the equation, different influencing-parameters are entered into the equation in order to sample the performance of that equation. Introducing a parameter into the equation is to be understood as adding this new influencing-parameter to the combination of equation-parameters and generating a new current equation on the basis of these equation-parameters, ie. the combination of influencing-parameters that now includes the newly introduced influencing-parameters. Each equation is generated by means of standard multiple regression analysis, generating a formula, wherein the equation-parameters are variables to the equation and the factors of influence the constants of each equation-parameter. Furthermore, a current equation is generated after removal of an influencing-parameter according to the method.

The introduction of the influencing-parameters or there exclusion respectively is done according to the following steps:

- 1) determining a significance value and a correlation value for each influencing-parameter with respect to the equation-parameter(s),
- 5 2) selecting as new equation-parameter the influencing-parameter with the highest significance and the lowest correlation that is not an equation-parameter and has according to a parameter-database not been used as equation-parameter in combination with the equation-parameters of the current equation,
- 10 3) replacing the current equation with a new current equation by generating the new current equation based on the equation-parameters now including the new equation-parameter by means of multiple regression analysis based on the values of the value-database,
- 4) recording in parameter-database the combination of influencing-parameters already used as equation-parameters and the order of introducing the  
15 equation-parameters into the current equation,
- 5) calculating the performance of the current equation and recording this performance with reference to the equation-parameters in the current equation in a performance-database
- 20 6) repeating the steps 1) to 5) until for none of the influencing-parameters that are not equation-parameters the significance is higher than a predetermined value while at the same time the correlation is lower than a predetermined value or either the significance of an equation-parameter has become lower than a predetermined value or the correlation of an equation-parameter becomes higher than a predetermined value,  
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- 7) excluding the influencing-parameter that according to the parameter-database was last selected as new equation-parameter and replacing the current equation with a new current equation by generating the new current

equation based on the equation-parameters that remain after exclusion of the last selected influencing-parameter by means of multiple regression analysis based on the values of the value-database,

- 8) repeating the steps 1) to 7) until the influencing-parameter to be excluded  
5 is the start value.

This leads to a series of tried combinations as shown in Fig. 1. Starting from the intercept a significance value (Prob>F) and a correlation value (VIF) for each influencing-parameter with respect to the only equation-parameter (the  
10 intercept) is calculated. The result is shown in Fig. 2. This shows that influencing-parameter 1 has the highest significance (Prob>F has the lowest value) and the lowest correlation (VIF has the lowest value) that satisfy the selected predetermined levels of Prob>F less than 0,05 and VIF<5. Since  
15 influencing-parameter 1 has not been tried as equation-parameter in combination with the intercept, influencing parameter 1 is selected as new equation-parameter and introduced into the equation and the new current equation is generated.

Calculating the significance value and the correlation value of the influencing-parameters in relation to the new combination of equation-parameters  
20 (intercept, 1) leads to the results shown in Fig. 3. Here influencing-parameter 3 is selected as new influencing-parameter to be introduced as equation-parameter, as the correlation is the lowest, the significance is the highest and influencing-parameter 3 has not been tried as equation-  
25 parameter in combination with the influencing-parameters already in the equation (intercept, 1). The new current equation is generated.

When calculating Prob>F and VIF for the influencing-parameters in relation to the new combination of equation-parameters, no further influencing-parameter can be selected as new equation-parameter, as no influencing-parameter not yet equation-parameter has a Prob>F value lower than 0,05 and a VIF value of lower than 5 (cf. Fig. 4). While normally this would be expected to be the best model, as the values with the lowest correlation and the highest significance have been introduced into the equation, the method according to the invention teaches to continue combining influencing-parameters into equations by first removing the last introduced influencing-parameter (3). This leads to an equation with results as shown in Fig. 3

Though influencing-parameter 3 has - as was said above - the lowest correlation value and lowest significance value (ie. highest significance) at this level, according to the method it can not be selected at this stage, as it has already been tried in combination with the current equation-parameters (intercept, 1). Thus according to the method influencing-parameter 5 is selected as new equation-parameter, as it has a significance that is higher than a predetermined value (Prob>F is less than 0,05) and has a correlation that is lower than a predetermined value ( $VIF < 5$ ) and also has not been tried in combination with the current equation-parameters (intercept, 1). With this set of equation-parameters (intercept, 1, 5) a new current equation is generated.

As shown in Fig. 5, only the significance value and the correlation value of influencing-parameter 3 allow its selection as new equation-parameter, as only these are lower than the predetermined values. Thus a new current equation is generated on the basis of this combination of equation-parameters.

Fig. 6 shows that by introducing influencing-parameter 3 into the equation, the significance value of influencing-parameter 5 became higher than the predetermined value (Prob>F equals 0,4142 which is  $> 0,05$ ). Thus influencing-parameter 5 became insignificant. According to the method, no new equation-parameter can be selected at this stage, but the last introduced influencing-parameter has to be removed, ie. influencing-parameter 3. Note that according to the method, not the influencing-parameter that became insignificant (5), but the last introduced influencing-parameter (3) is excluded. The situation thus returns to the combination shown in Fig. 5. Here it can be seen that no other influencing-parameter satisfies the conditions for significance and correlation apart from influencing-parameter 3, which can not be selected as it has already been tried in combination with the current equation parameters (intercept, 1, 5). Thus, according to the method, the last influencing-parameter introduced into the equation that led to this situation is removed from the equation, ie. influencing parameter 5. This leads to a situation as shown in Fig. 3. Once again, no influencing-parameter can be selected, that satisfies the conditions for significance and correlation that at the same time has not been tried as equation-parameter in combination with the current equation-parameters (intercept, 1). Thus the last influencing-parameter entered into the equation that led to this situation has to be removed, ie. influencing-parameter 1. This leads to the situation shown in Fig. 2.

Fig. 2 shows, that apart from influencing-parameter 1, which has already been tried in combination with the current equation-parameter (intercept), Influencing-parameters 3, 5 and 4 satisfy the conditions for correlation and significance. Of these, influencing-parameter 3 has the lowest correlation

and highest significance (lowest Prob>F value) and is thus selected as new equation-parameter. The result is shown in Fig. 7.

5     Though here influencing-parameter 1 shows the lowest correlation and highest significance, since the combination of influencing-parameters intercept, 1 and 3 has already been tried as shown in Fig. 4, influencing-parameter 1 can not be selected as new influencing-parameter at this stage. Thus influencing-parameter 4 is selected, as it satisfies the conditions for significance and correlation and at the same time has not been tried as  
10    equation-parameter in combination with the current equation-parameters (intercept, 3). A new current equation is generated.

Fig. 8 shows the correlation and significance of the influencing-parameters in relation to the equation-parameters (intercept, 3,4). It can be seen that  
15    here influencing-parameter 5 can be selected as new equation-parameter as it satisfies the above mentioned conditions and has not been tried in combination with the equation-parameters (intercept, 3, 4). A further current equation is generated.

20    As can be deducted from Fig. 9, no new equation-parameter can be selected, as none of the influencing-parameters that are not equation-parameters satisfies the conditions. Thus according to the method, the last introduced influencing-parameter is removed from the equation, ie. influencing-parameter 5. This leads to a situation as shown in Fig. 8.

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Since influencing-parameter 5 can now not be selected, as it has already been tried in combination with the current equation-parameters (intercept, 3,4), only influencing-parameter 1 can be selected, as it satisfies the above



mentioned conditions, ie. has a correlation value that is lower than the pre-determined value ( $VIF < 5$ ) and a significance value that is lower than a pre-determined value ( $Prob > F$  is less than 0,05). With the selected influencing-parameter 1 a new current equation is generated.

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As shown in Fig. 10, the introduction of influencing-parameter 1 causes influencing-parameter 4 (an equation-parameter) to become insignificant. According to the method, no further influencing-parameter is selected as equation-parameter, but the last introduced influencing-parameter (1) is removed. This leads to the same situation as shown in Fig. 8. Here it can be seen that no other influencing-parameter satisfies the conditions for significance and correlation apart from influencing-parameter 5, which can not be selected as it has already been tried in combination with the current equation parameters (intercept, 3, 4). Thus, according to the method, the last influencing-parameter introduced into the equation that led to this situation is removed from the equation, ie. influencing parameter 4. This leads to a situation as shown in Fig. 7. Once again, no influencing-parameter can be selected, that satisfies the conditions for significance and correlation that at the same time has not been tried as equation-parameter in combination with the current-equation parameters (intercept, 3). Thus the last influencing-parameter entered into the equation that led to this situation has to be removed, ie. influencing-parameter 3. This leads to the situation shown in Fig. 2.

25 Fig. 2 shows, that apart from influencing-parameters 1,3, which have already been tried in combination with the current equation-parameter (intercept), influencing-parameters 5 and 4 satisfy the conditions for correlation and significance. Of these, influencing-parameter 5 has the

lowest correlation and highest significance (lowest Prob>F value) and is thus selected as new equation-parameter. The result is shown in Fig. 11.

5 As influencing-parameter 1 has already been tried in combination with the current equation parameters (intercept, 5) as seen in Fig. 5, only influencing-parameter 3 remains that can be selected as new equation-parameter according to the above conditions. The new current equation generated on the basis of this combination of influencing parameters (intercept, 5,3) leads to a situation as shown in Fig. 12.

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There it can be seen that by introducing influencing-parameter 3 into the equation, influencing-parameter 5 (an equation-parameter) has been made insignificant. Thus according to the method the last introduced influencing-parameter is removed (influencing-parameter 3), which leads to a situation shown in Fig. 11 from which no further influencing-parameter can be removed. Accordingly, the last introduced influencing-parameter, that led to this situation, is removed (influencing-parameter 5), which leads to a situation shown in Fig. 2.

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20 Fig. 2 shows, that apart from influencing-parameters 1,3,5, which have already been tried in combination with the current equation-parameter (intercept), influencing-parameter 4 satisfies the conditions for correlation and significance. Thus this is selected as new equation-parameter. The result is shown in Fig. 13.

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As influencing-parameter 3 has already been tried in combination with the current equation parameters (intercept, 4) as seen in Fig. 8, only influencing-parameter 1 remains that can be selected as new equation-parameter

according to the above conditions. The new current equation generated on the basis of this combination of influencing parameters (intercept, 4,1) leads to a situation as shown in Fig. 14.

5 There it can be seen that by introducing influencing-parameter 3 into the equation, influencing-parameter 4 (an equation-parameter) has been made insignificant. Thus according to the method the last introduced influencing-parameter is removed (influencing-parameter 1), which leads to a situation shown in Fig. 13 from which no further influencing-parameter can be  
10 removed. Accordingly, the last introduced influencing-parameter, that led to this situation, is removed (influencing-parameter 5), which leads to a situation shown in Fig. 2. From here, no other influencing-parameter can be selected as new equation-parameter, which according to the method would lead to the last entered influencing-parameter to be removed. Since this is  
15 however the start-value (intercept) the process of introducing/removing influencing-parameters is halted at this stage.

Now the equation that provided the best performance needs to be selected. During each calculation step for a new current equation, the performance of  
20 the current equation was calculated and is represented in the respective Figs. These performance-values in relation to the combination of influencing-parameters in the equation that led to this performance are stored at each step in a performance-database. From this database the combination of influencing-parameters leading to the best performing  
25 equation (influencing-parameters 3,4,5 as can be seen from Fig. 9) is selected and the final equation is generated.

Current values taken from the operating furnace are fed into this equation, which then leads to a value for the probable coil life.

5 In order to aid determining which influencing-parameter can be added or which influencing-parameter has to be removed as last introduced influencing-parameter, at each step a parameter-database keeps record of what combinations have already been tried and in what order the influencing-parameters were introduced into the equation.

10 From this example it can be seen that the method according to the invention leads to a result, that would previously not be expected. Instead of only introducing strong influencing-parameters into the equation, ie. those that have a very low correlation and a very high significance, according to the method also less strong variables are tried. Traditionally, the model as  
15 shown in Fig. 4 would be considered as best model. However comparing the performances shows, that the combination of Fig. 9 leads to the best performing model.

20 The method according to the invention not only leads to a better model, but also reduces calculation time and hardware necessary to obtain this better model. According to the method, not all possible combinations of influencing-parameters as equation-parameters have to be tried, which would lead to immense calculation times and would make fast calculating machines necessary, but only a special selection of combinations is tried.

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